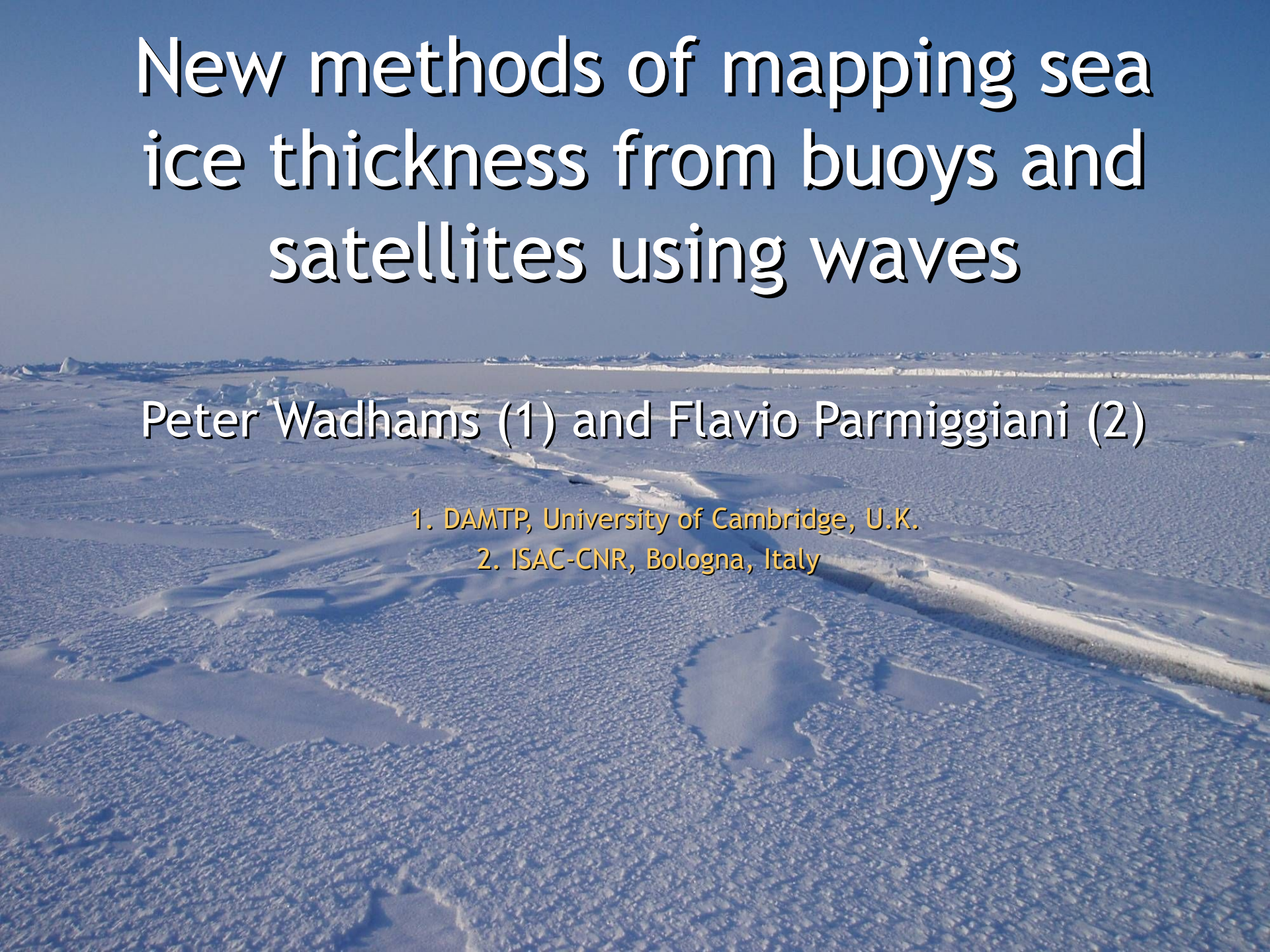
New methods of mapping sea ice thickness from buoys and satellites using waves



Peter Wadhams (1) and Flavio Parmiggiani (2)

1. DAMTP, University of Cambridge, U.K.
2. ISAC-CNR, Bologna, Italy

Colleagues

TILTMETERS

Martin Doble - DAMTP, Cambridge and LOV, Villefranche
Jeremy Wilkinson – SAMS, Oban

SAR PANCAKE METHOD

Flavio Parmiggiani – ISAC-CNR, Bologna
Giacomo de Carolis – CNR, Bari

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SEA ICE CHANGES AND THEIR MEASUREMENT

Arctic sea ice. There has been a dramatic decrease in arctic sea ice in the last three decades, as indicated by

- a **shrinking** of the boundaries (3-4% per decade, rising to 8-9% recently)
- a **thinning** of the interior ice cover (43% in 25 years)

The shrinking can be measured by satellites, but the thinning can best be measured by repeated direct profiling by a technique which gives the whole of the probability density function of thickness (e.g. sonar from submarines).

Greenland Sea. Ice retreat from the central Greenland Sea is associated with reduction in the depth and volume of winter convection, slowing the Atlantic Thermohaline Circulation.

Antarctic. No evidence of sea ice retreat or thinning, but thickness measurements are currently totally inadequate.

METHODS THAT CAN BE USED IN THE ABSENCE OF SONAR

When upward sonar (submarines, AUVs, moorings, floats) is unavailable, other methods offer a part of the pdf. They include

- **electromagnetic sounding** – gives whole pdf but does not respond fully to first-year pressure ridges
- **scanning laser profiling –** gives freeboard of ice plus snow, ice thickness must be inferred
- **radar or laser altimetry** from satellites (CryoSat, ICESat) – give area-averaged freeboards from which thickness must be inferred

Two new techniques have been introduced and tested, based on different properties of ocean waves propagating through different types of ice

- **TILTMETER BUOYS** make use of dispersion relation of waves in continuous ice cover (idealised as elastic sheet)
- **SAR SPECTRAL ANALYSIS** makes use of dispersion relation of waves in frazil-pancake ice (idealised as viscous layer)

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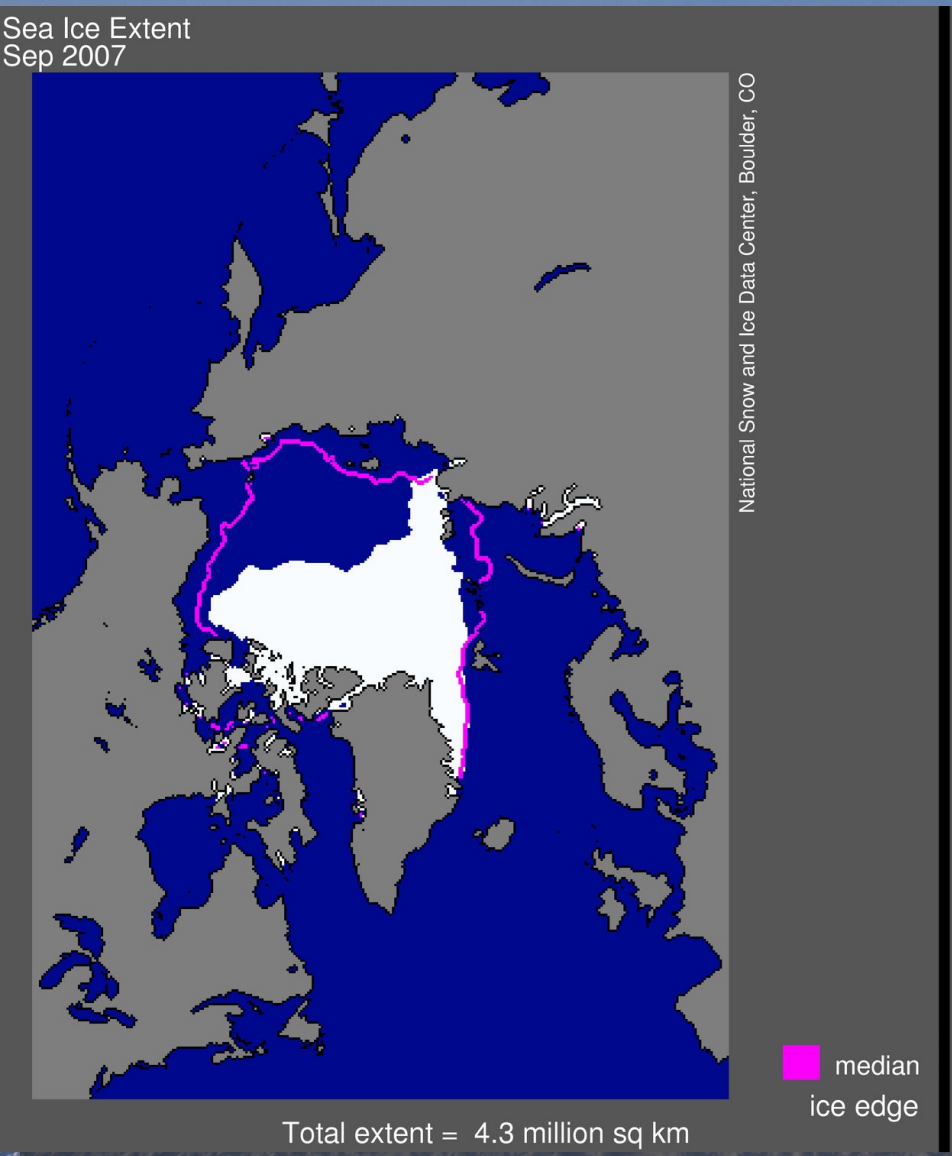
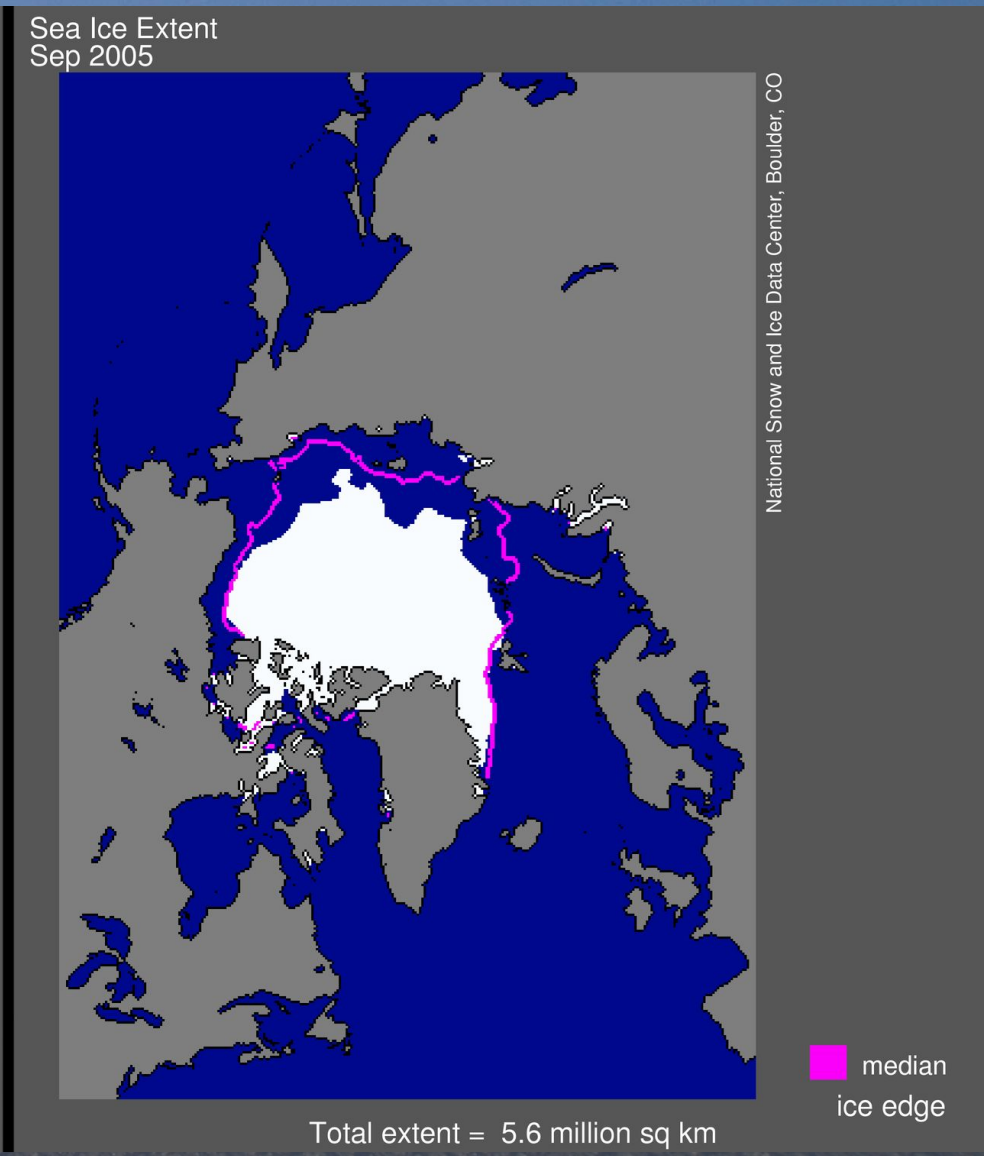
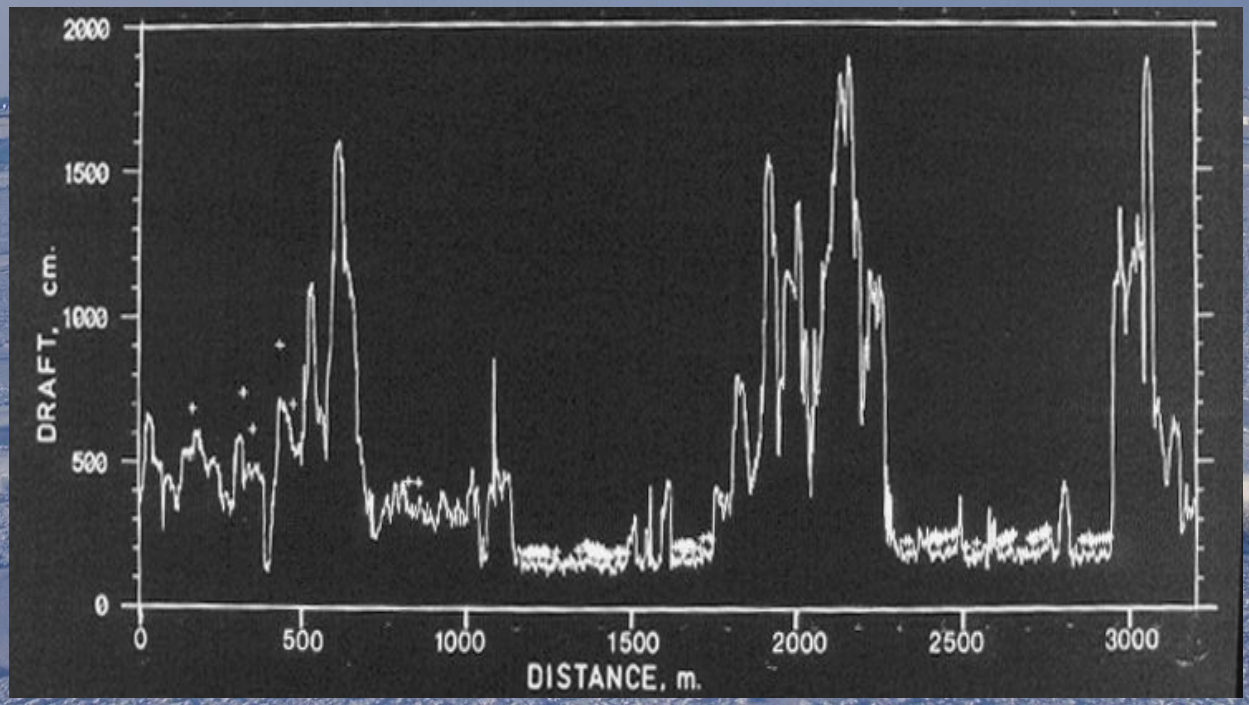
Record minimum ice extent in Sept. 2007



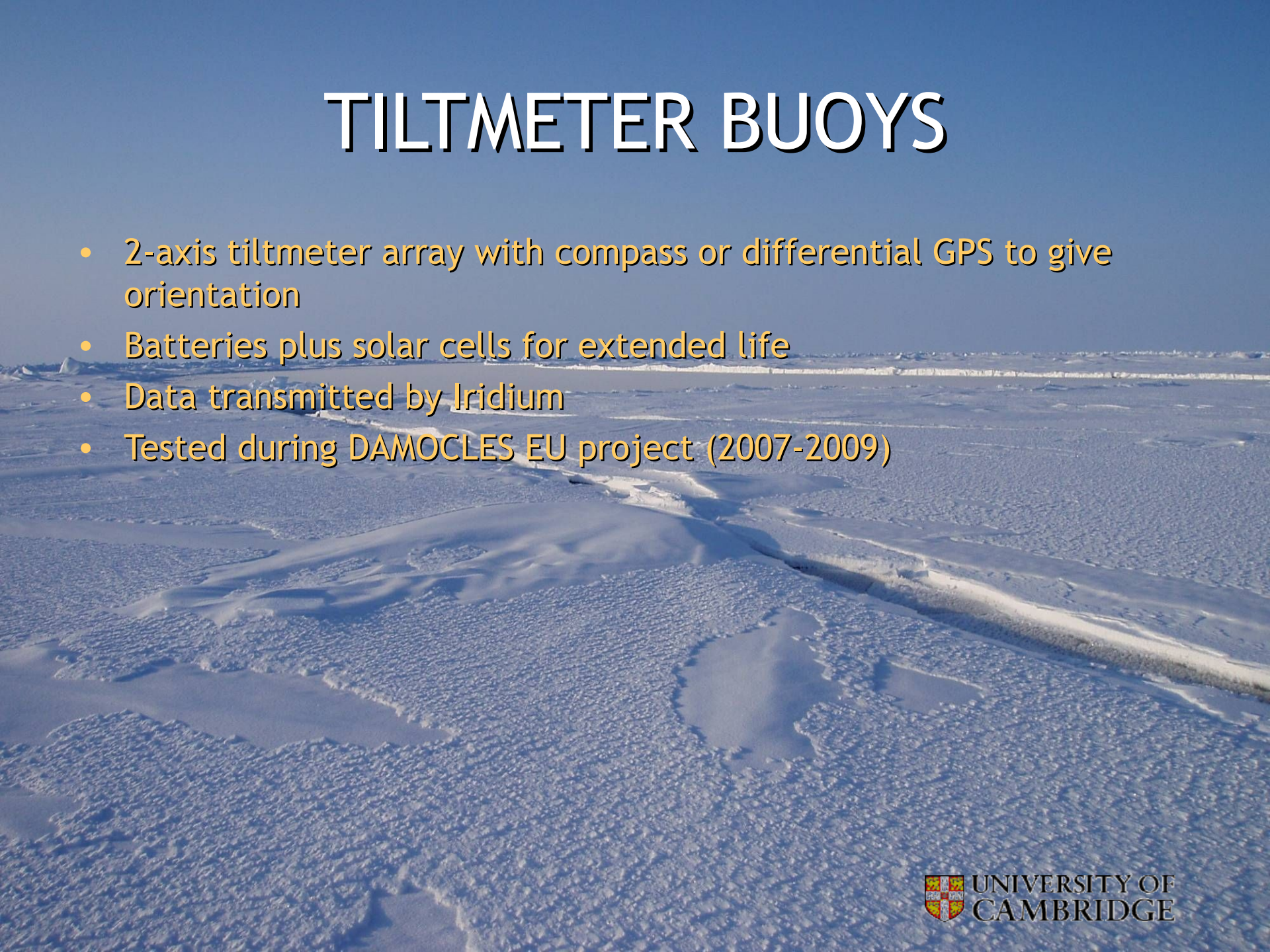


Upward sonar profile



TILTMETER BUOYS

- 2-axis tiltmeter array with compass or differential GPS to give orientation
- Batteries plus solar cells for extended life
- Data transmitted by Iridium
- Tested during DAMOCLES EU project (2007-2009)



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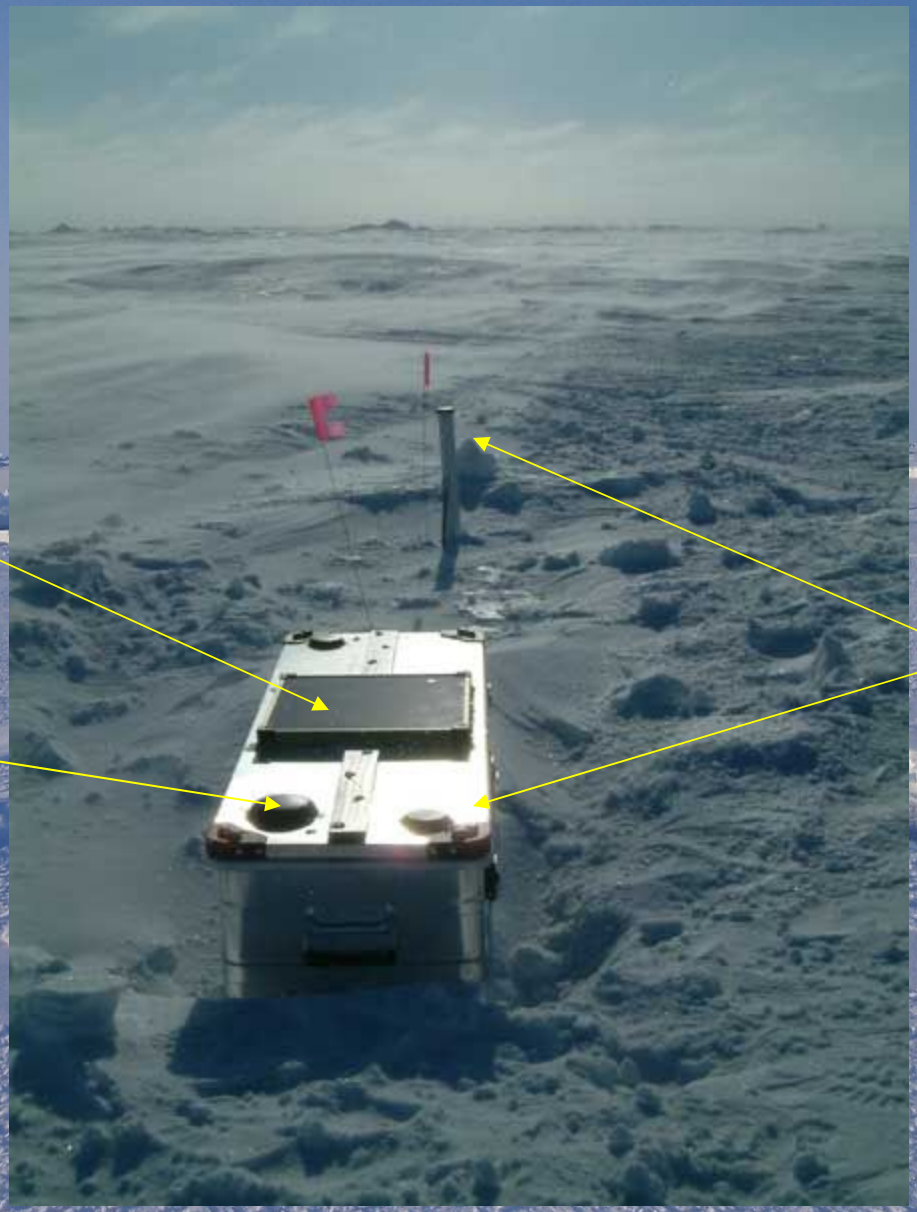
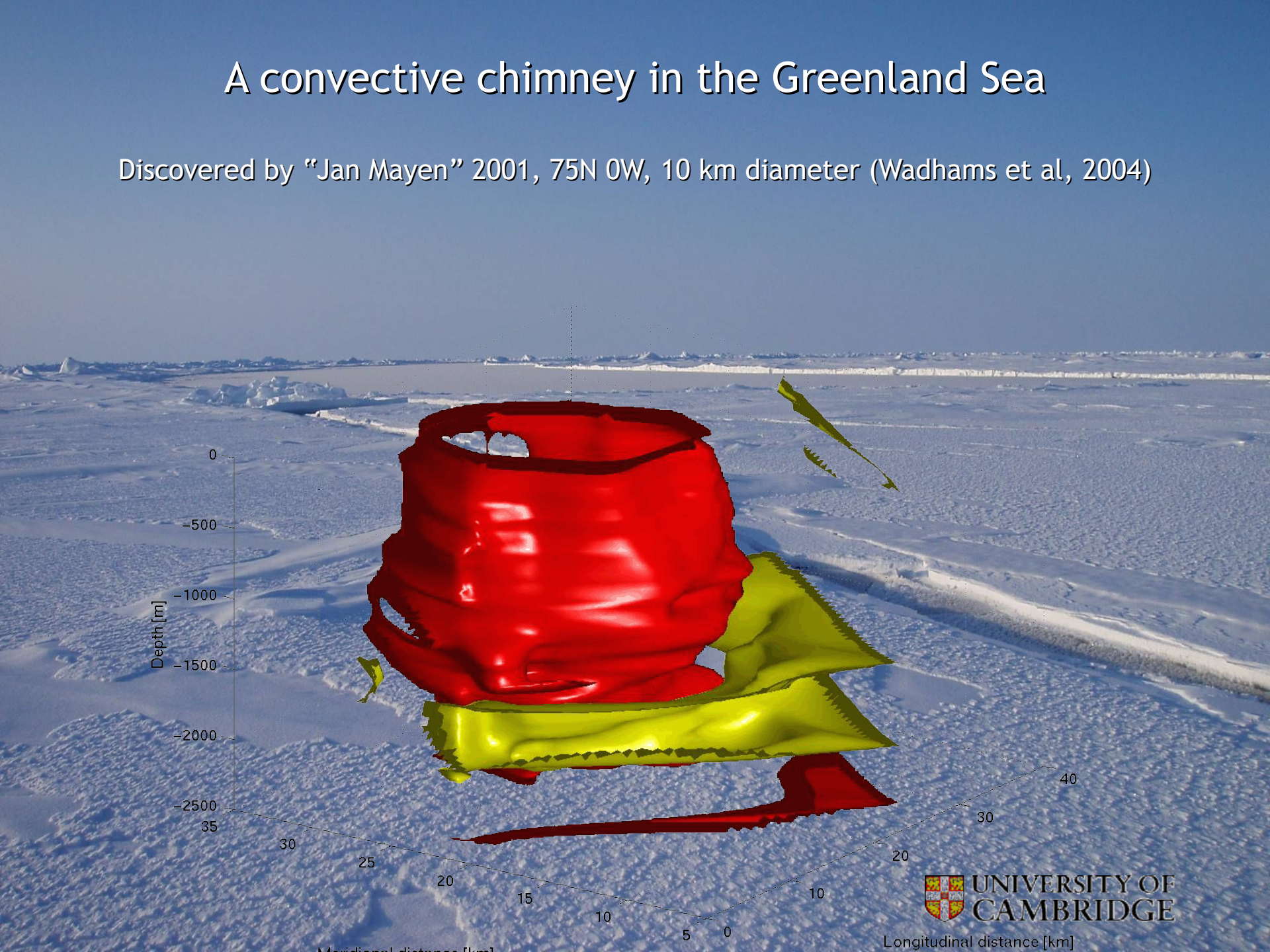
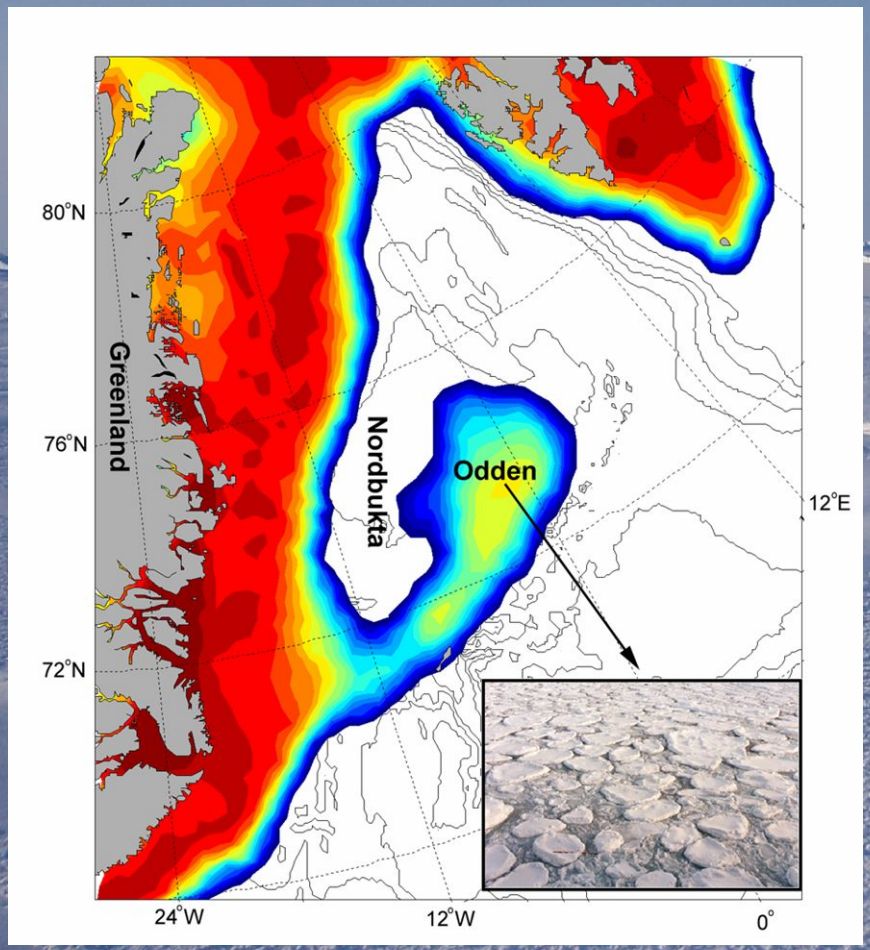

Solar panel
Iridium antenna
GPS antennae
4m apart to give
reliable heading
close to magnetic
Pole

A convective chimney in the Greenland Sea

Discovered by "Jan Mayen" 2001, 75N 0W, 10 km diameter (Wadhams et al, 2004)





Greenland Sea in a severe winter

Convective chimneys form in the Odden ice tongue

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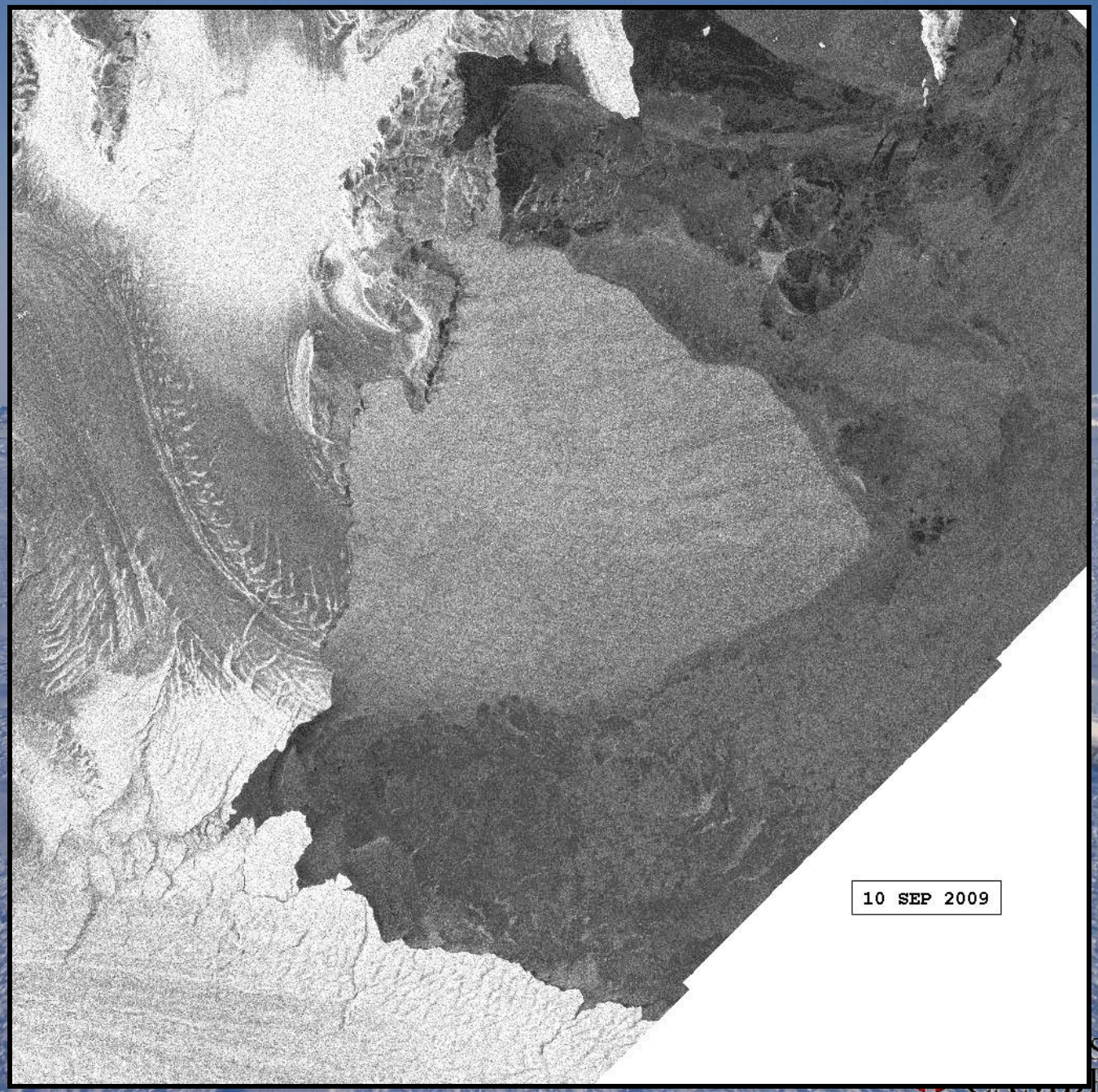

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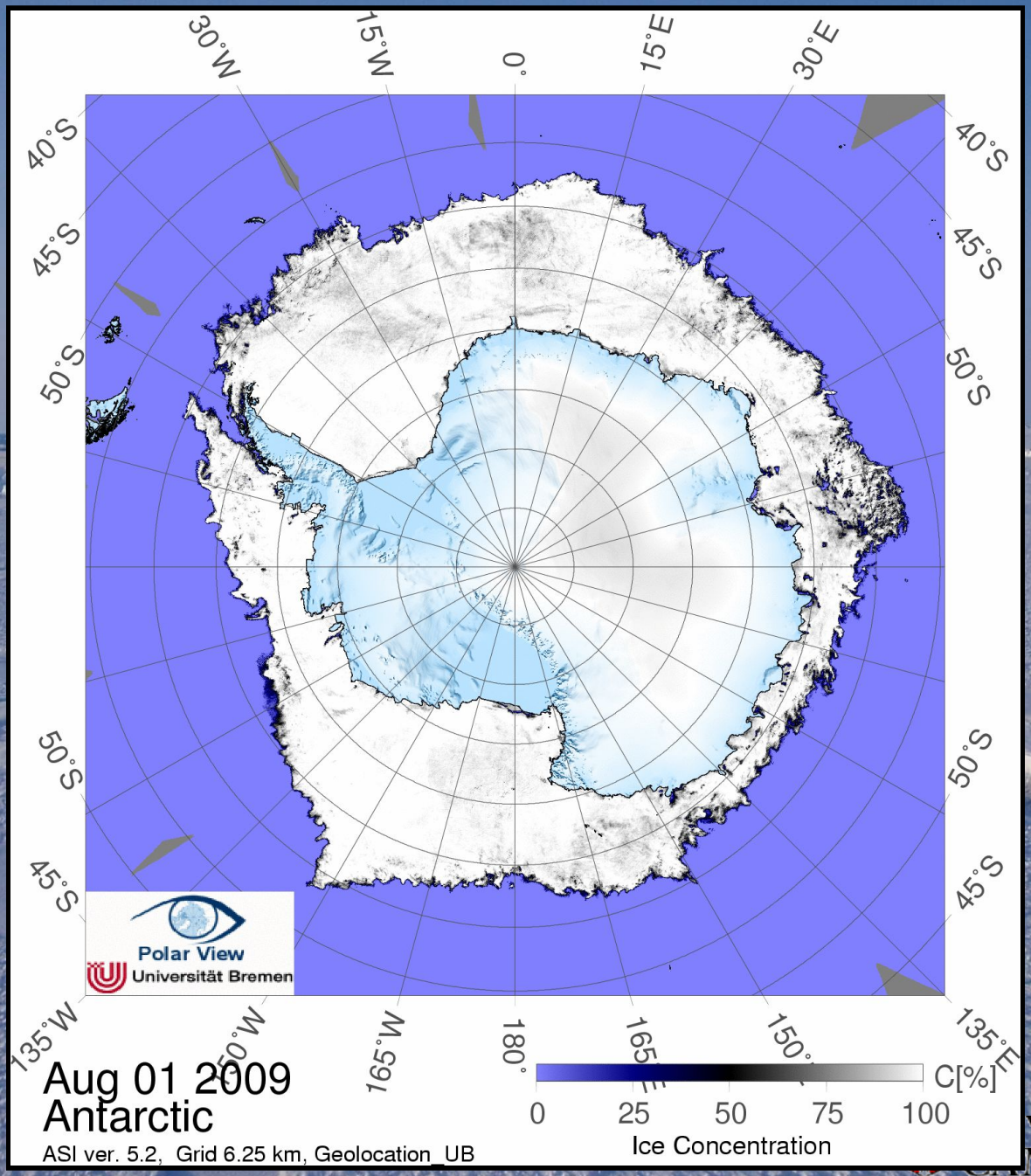
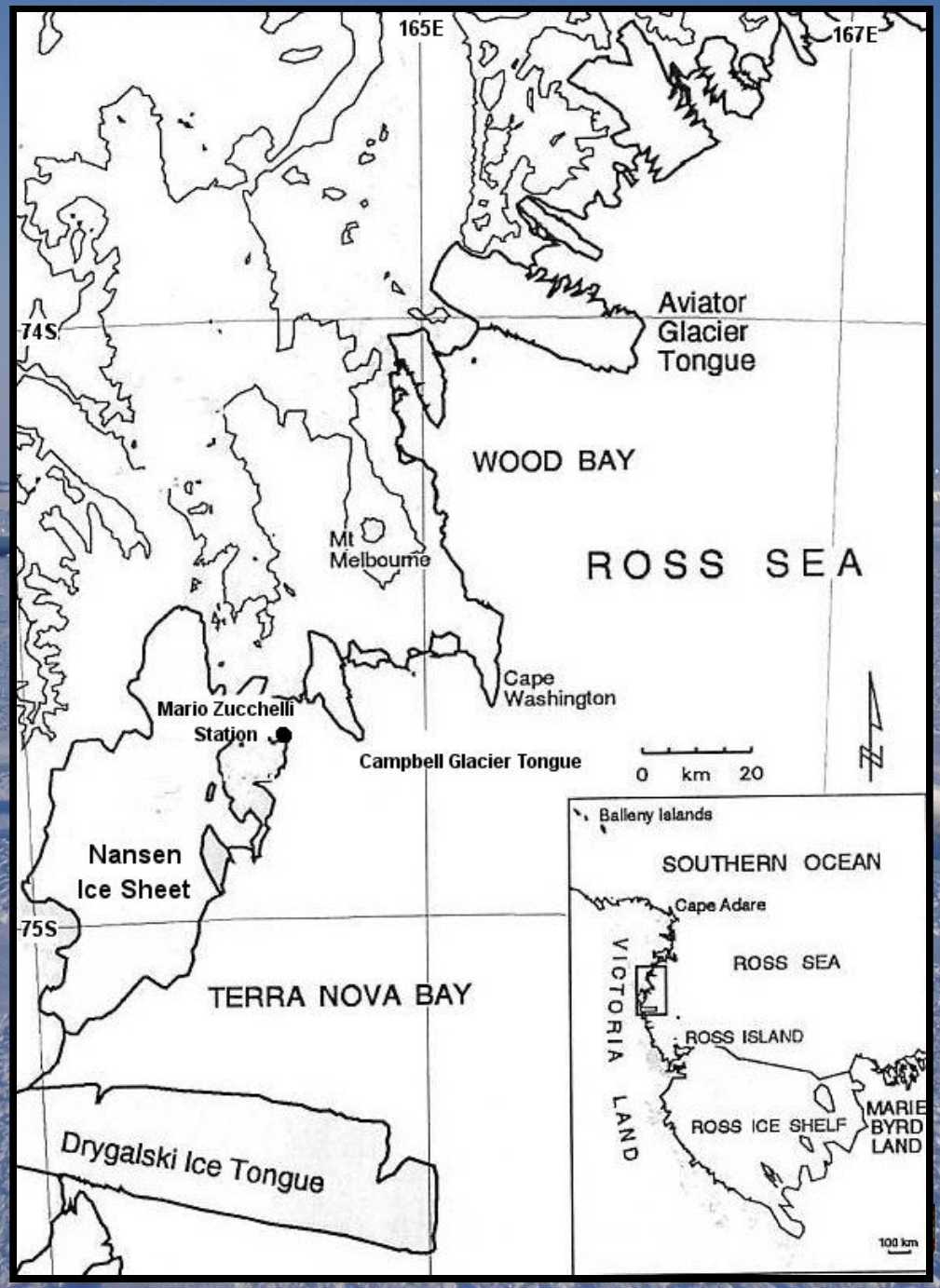
RIDGE


30°W
15°W
0°
15°E
30°E
40°S
45°S
50°S
50°S
45°S
135°W
150°W
165°W
180°
165°E
150°E
135°E
Polar View
Universität Bremen
Aug 01 2009
Antarctic
ASI ver. 5.2, Grid 6.25 km, Geolocation_UB
C[%]
0
25
50
75
100
Ice Concentration



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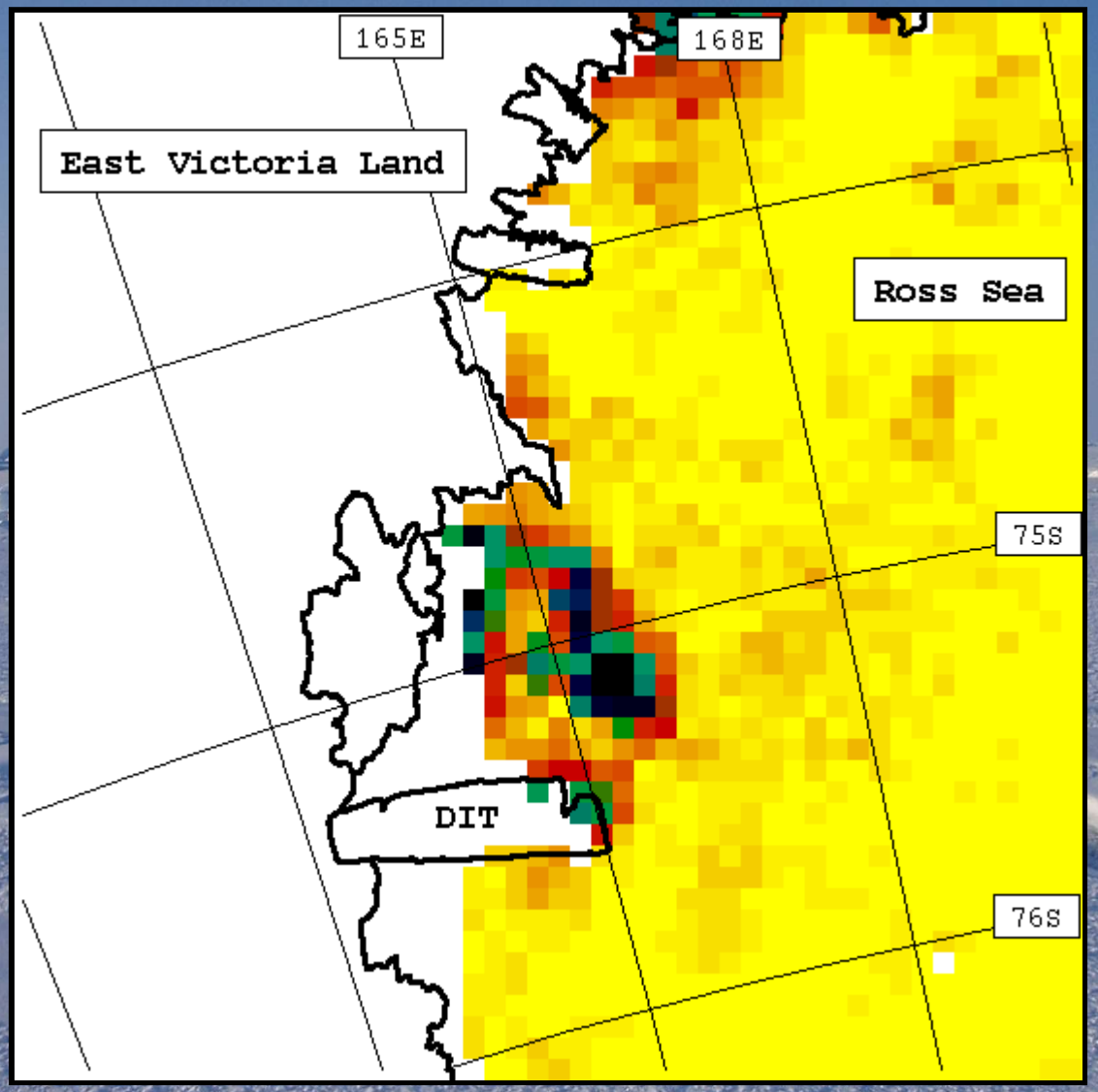

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Fig. 2

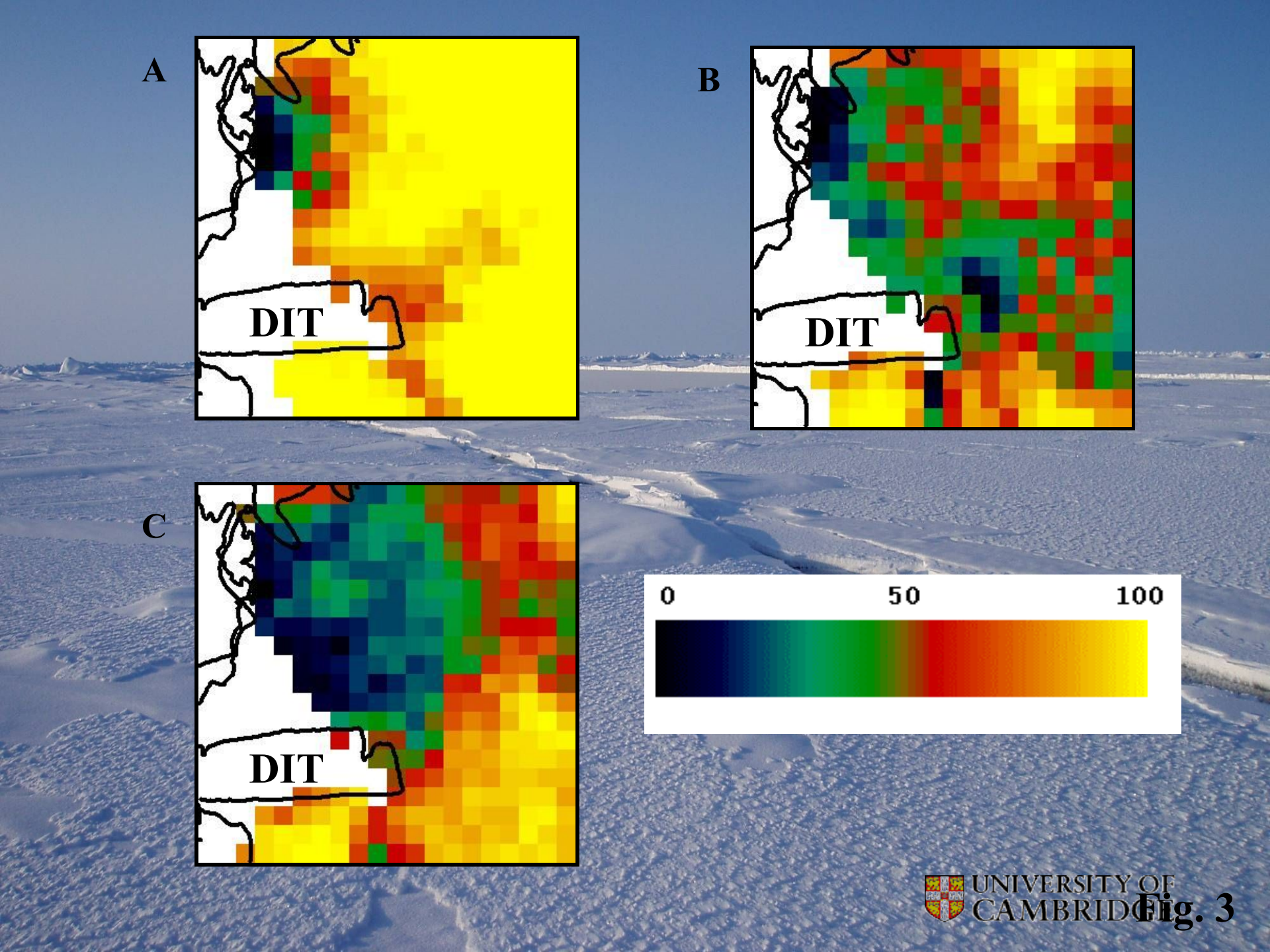

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Fig. 3

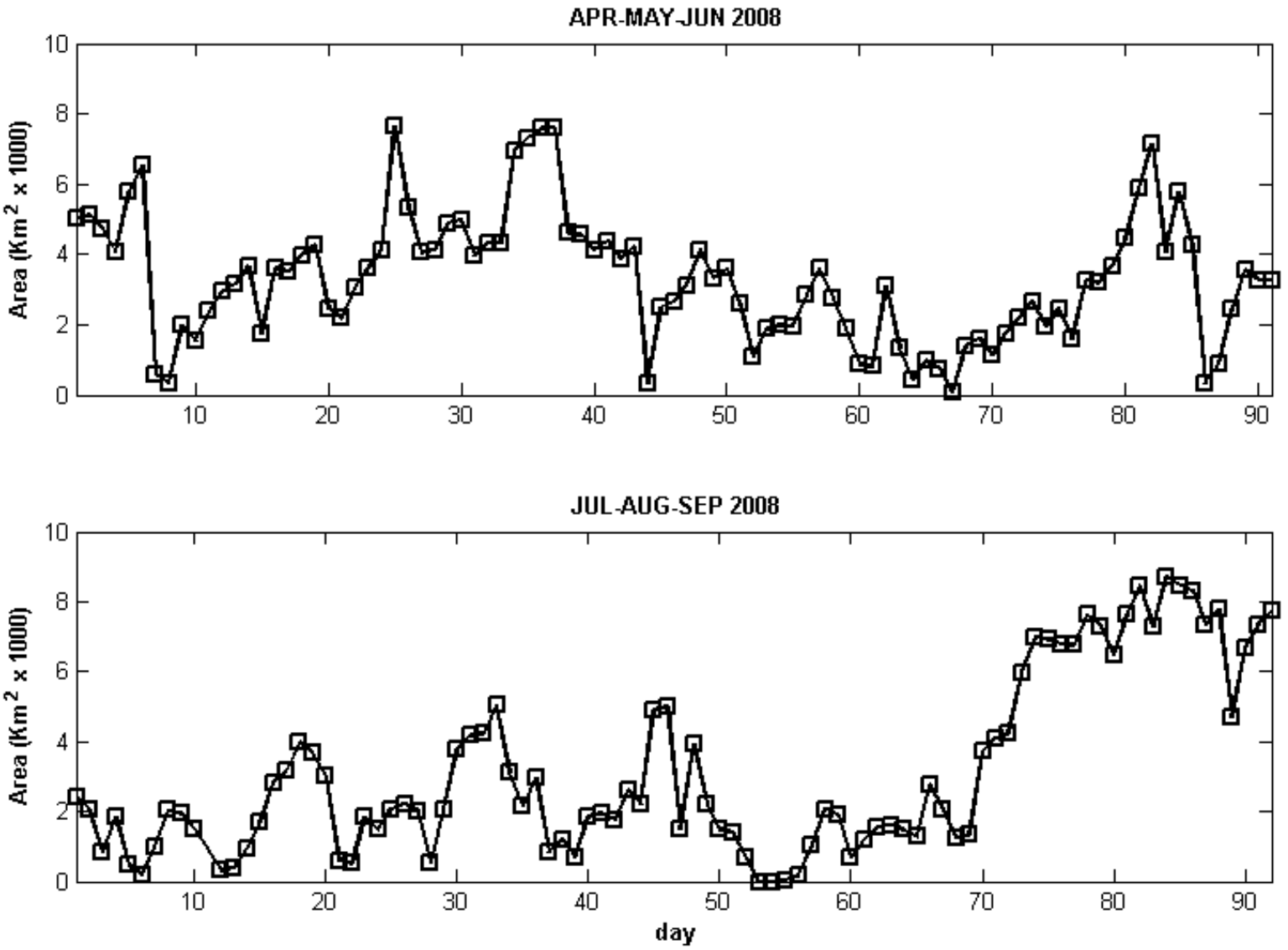

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Fig. 7

WAVES IN FRAZIL-PANCAKE ICE

It has been found from a long series of lab experiments (e.g. in Hamburg HSVA tank), field observations, and theoretical development, that waves propagate in frazil-pancake icefields with a different dispersion relation, which can be described by a model in which the frazil-pancake suspension is treated as a high viscosity fluid (De Carolis). Since the amplitude of ocean waves is not seriously diminished by passage through frazil-pancake ice, waves within frazil-pancake icefields can still be seen in SAR imagery, and hence spectral analysis methods can be used to find the change in wavelength of a given dominant wave component on entry into the ice. This allows ice thickness to be inferred.

Application to
Circumpolar Antarctic – about 40% of area of winter ice cover
Greenland Sea – Odden ice tongue area (critical region of winter convection)
Bering Sea

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Pancake ice within the Odden

Frazil Sampling

Wavebuoy

Pancake drifting buoy

pancake lifting

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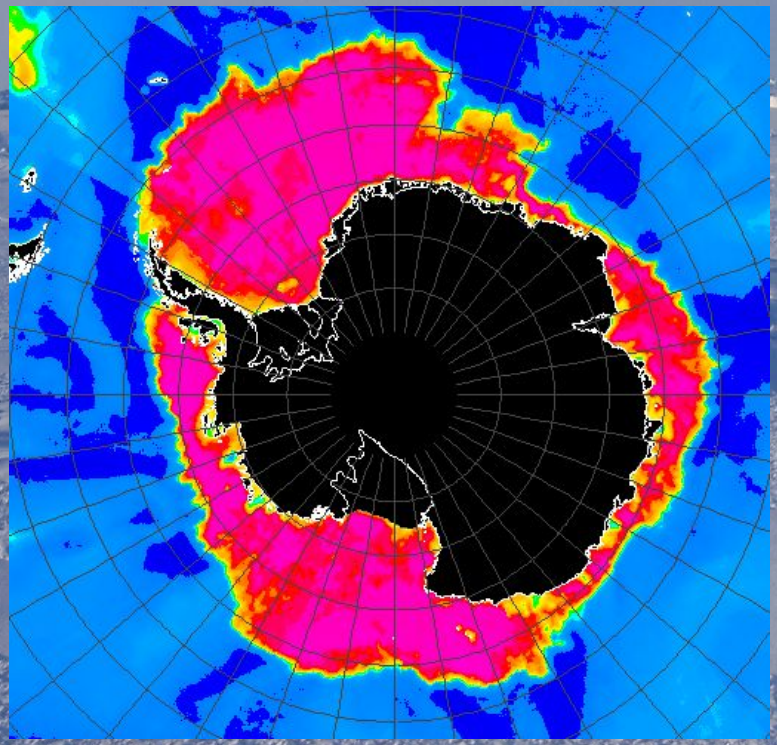
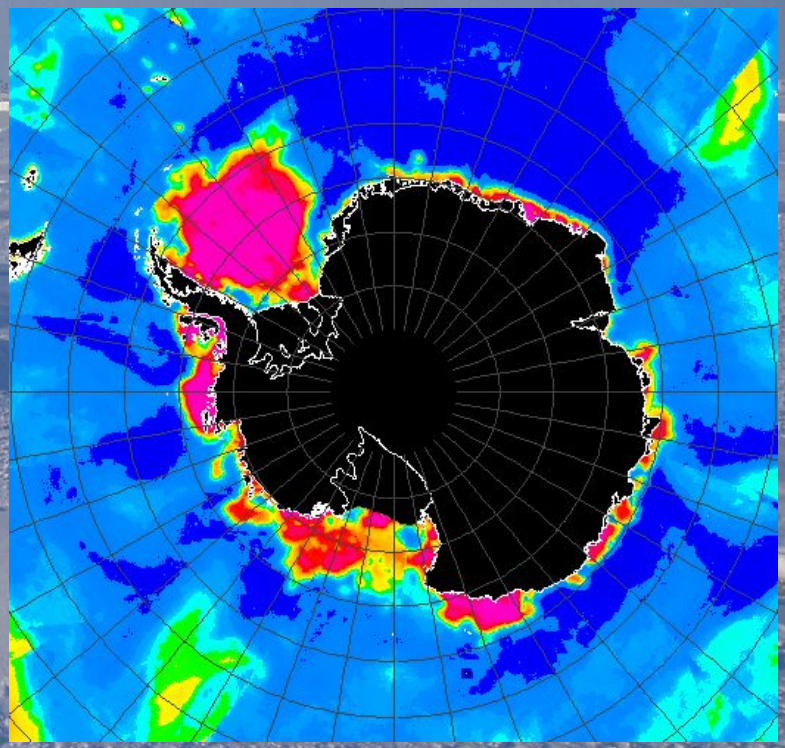
Antarctic sea ice extent

Winter (September) Summer (March)





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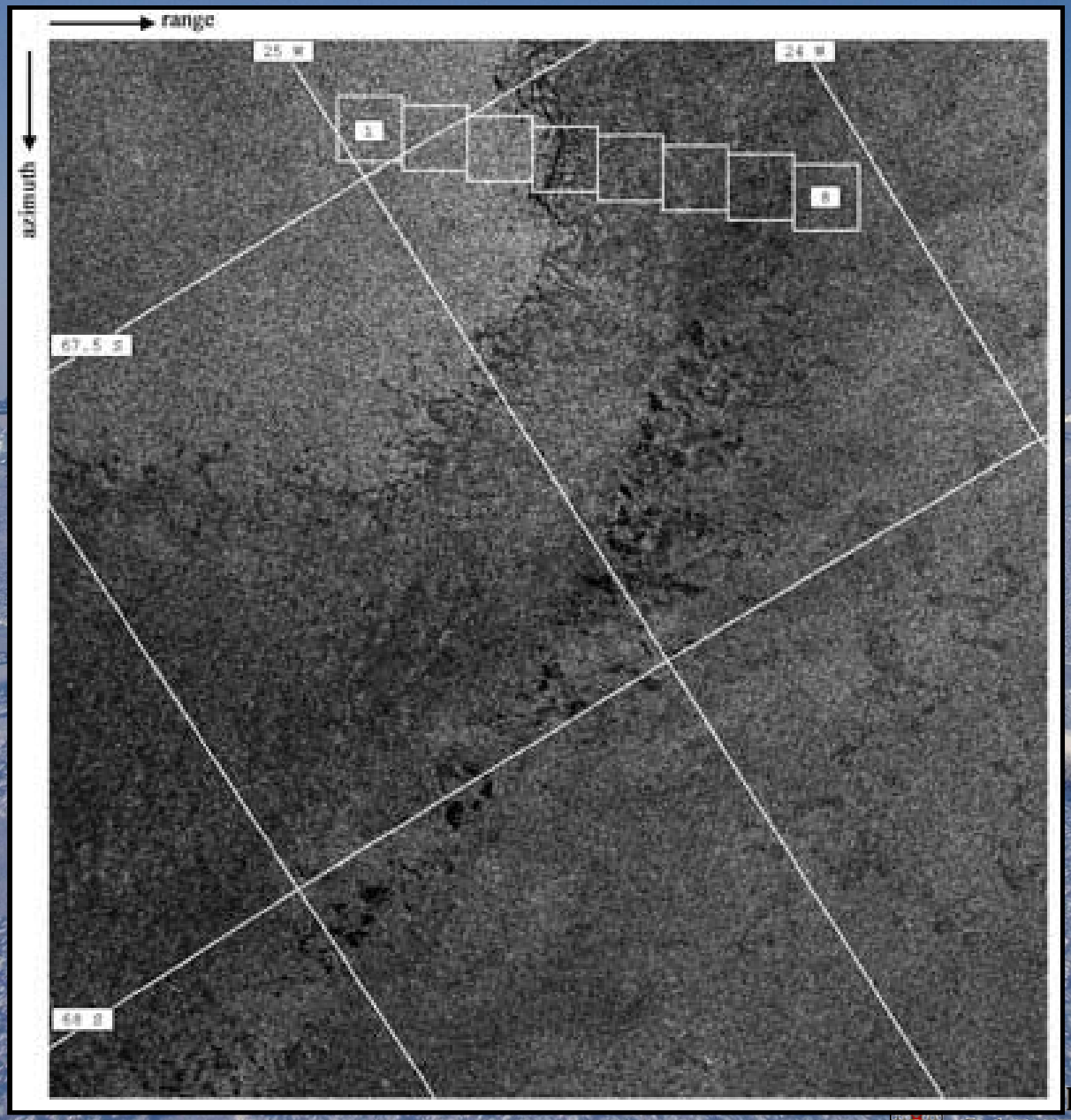

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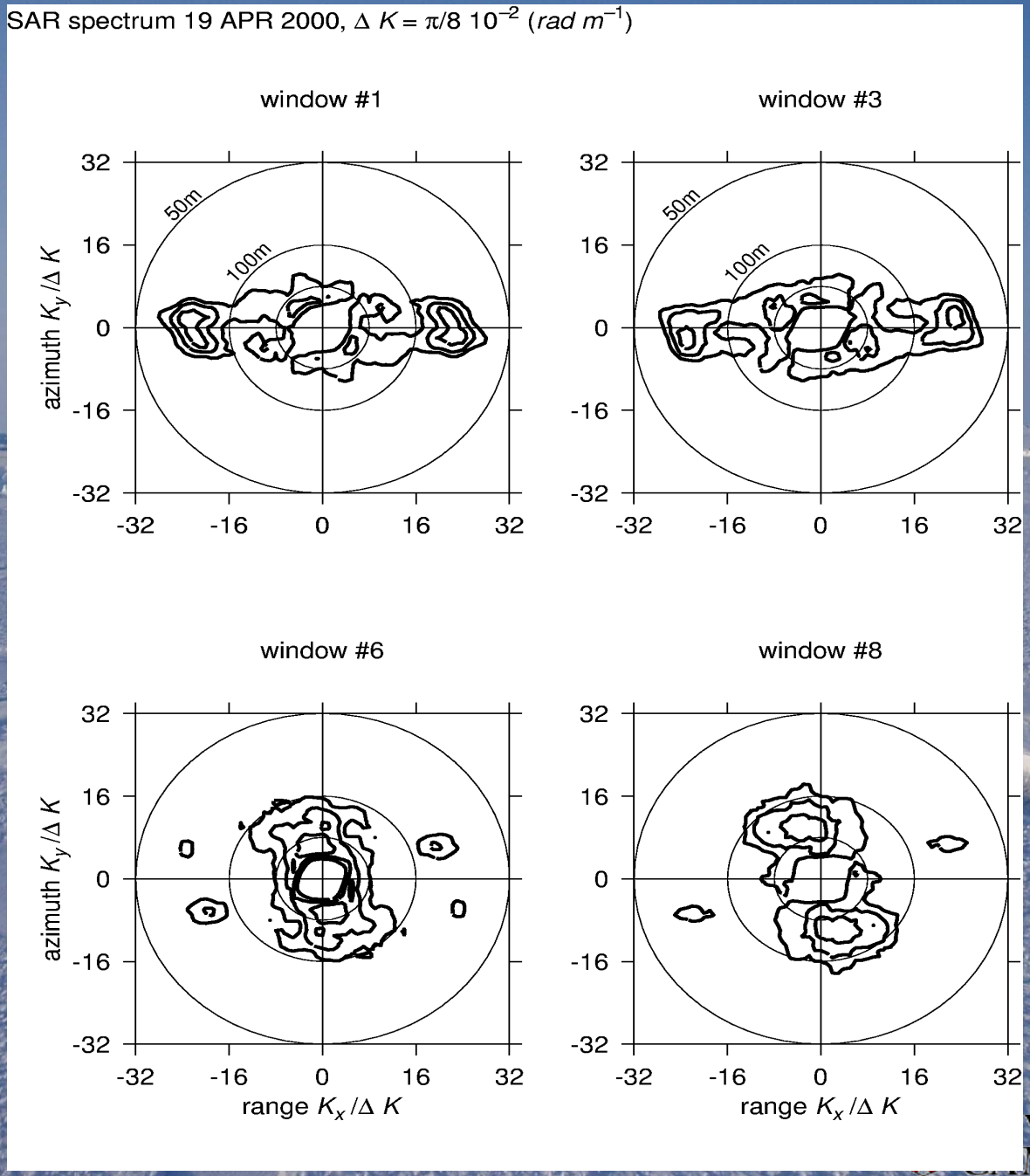
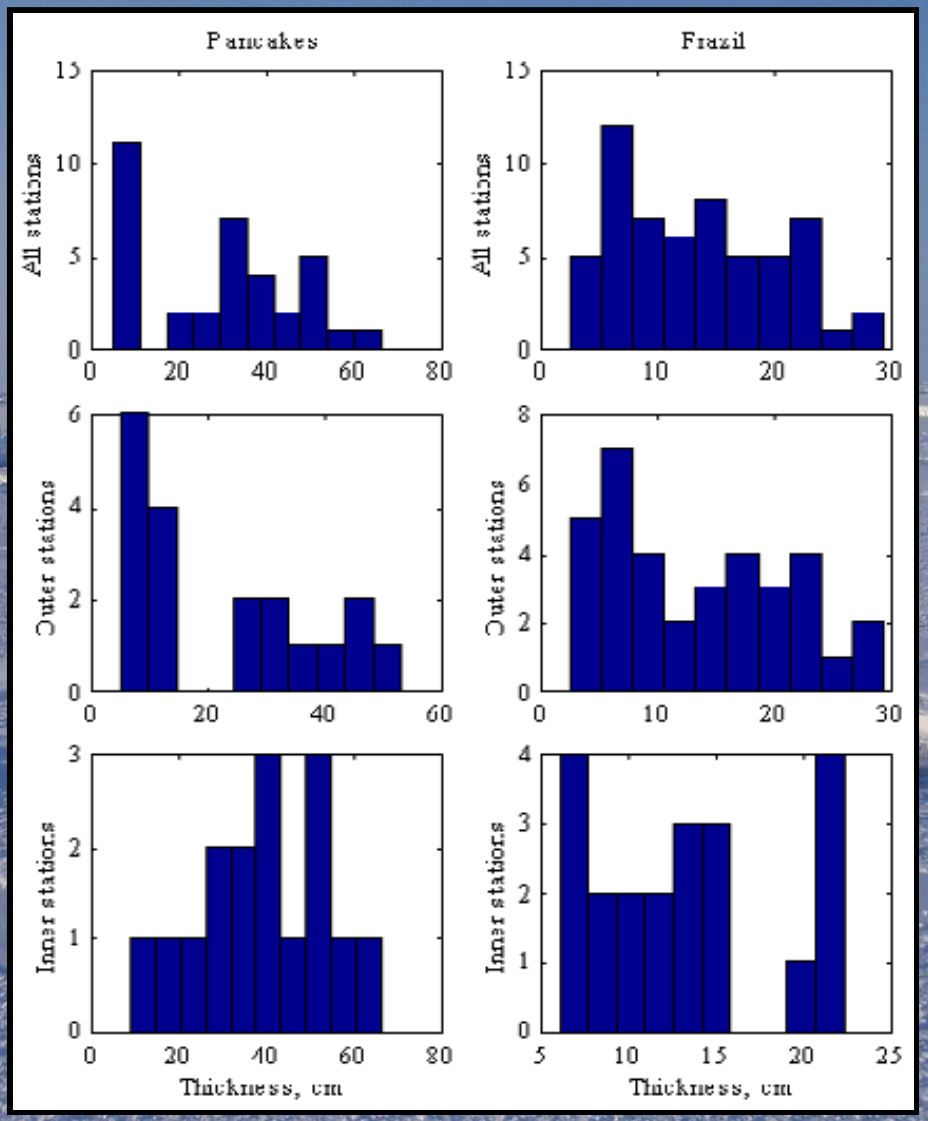

SAR spectrum 19 APR 2000, Δ K = π/8 10^-2 (rad m^-1)
window #1
window #3
window #6
window #8
50m
100m
azimuth Ky /Δ K
range Kx /Δ K
32
16
0
-16
-32



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Papers published

- TILTMETER BUOY METHOD: Wadhams, P. and M.J. Doble (2009), Sea ice thickness measurement using episodic infragravity waves from distant storms.

- FRAZIL-PANCAKE SPECTRAL METHOD: Wadhams, P., F. Parmiggiani, G. de Carolis, D. Desiderio and M.J. Doble (2004), SAR imaging of wave dispersion in Antarctic pancake ice and its use in measuring ice thickness. Geophys. Res. Lett. 31, doi:10.1029/2004GL020340

- POLYNYA: F. Parmiggiani (2006), Fluctuations of Terra Nova Bay polynya as observed by active (ASAR) and passive (AMSR-E) microwave radiometers. Int. J. Remote Sensing, 27, 2459-2467.

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Polar bears are unlikely to survive as a species if there is an almost complete loss of summer sea-ice cover - *Arctic Climate Impact Assessment 2005*

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